Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, DC

WT Docket No. 12-269

In the Matter of

Policies Regarding Mobile Spectrum Holdings

Bringing Weight to the Spectrum Screen: A Response to AT&T (revised¹)

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¹ The original version of this filing had the wrong graph in Figure 2. This has been corrected. Nothing other than Figure 2 has changed in this revision.

1 Executive Summary

An effective spectrum screen should help the regulator determine the extent to which each carrier's spectrum holdings in a given market have the potential to undermine competition. This can be achieved if the screen takes into account both the bandwidth and frequency of every spectrum license in a market. Like licenses with greater bandwidth, licenses at lower frequencies allow a carrier to build out at lower cost, so these licenses have greater value. The FCC should incorporate a frequency-based weighting function into the spectrum screen so that both frequency and bandwidth are adequately reflected. There is no rational basis for a policy of giving equal weight per MHz to licenses with very different frequencies; such a policy should be viewed as both arbitrary and counterproductive. This comment expands on a previous comment² to make these points, and it specifically refutes a reply comment from AT&T³ which includes statements from Drs. Jeffrey H. Reed, Nishith D. Tripathi, Mark A. Israel and Michael L. Katz.

2 Author Qualifications and Disclaimer

In writing this comment, Jon Peha represents no one but himself.

Jon M. Peha is a Full Professor at Carnegie Mellon University in the Dept. of Electrical & Computer Engineering and the Dept. of Engineering & Public Policy, and former Associate Director of CMU's Center for Wireless & Broadband Networking. His past government service includes positions at the Federal Communications Commission as Chief Technologist, at the White House as Assistant Director of the Office of Science and Technology Policy, in the House Energy & Commerce Committee as Legislative Fellow, and at USAID as leader of the Telecom Leadership program. His industry positions include Chief Technical Officer of Cyphermint, VTLinx Multimedia, and Proxicast, and member of technical staff at SRI International, AT&T Bell Labs, and Microsoft. He holds a Ph.D. in electrical engineering from Stanford, and a BS from Brown. Dr. Peha is a Fellow of the IEEE, a Fellow of the AAAS, and a member of FCBA and SHPE. He received the FCC's "Excellence in Engineering Award" and the IEEE Communications Society's TCCN Publication Award for career contributions. He consults on a wide range of technical and policy issues related to information and communications technology.

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² J. M. Peha, "Updating the Spectrum Screen," in the matter of Policies Regarding Spectrum Holdings and The State of Mobile Competition, WT Docket No. 12-269 and WT Docket No. 11-186, Nov. 28, 2012. http://apps.fcc.gov/ecfs/document/view?id=7022067749 Henceforth Peha, "Updating the Spectrum Screen," Nov. 28, 2012.

³ "Reply Comments of AT&T Inc.," in the matter of Policies Regarding Spectrum Holdings, WT Docket No. 12-269, Jan. 7, 2013.

http://apps.fcc.gov/ecfs/document/view;jsessionid=cWxHQtJRCsjkYtdLn7QYKc15VWL1Fp5sNQJsWDg6kTQ82lCnvSfk!956499833!471072203?id=7022100194 Henceforth "Reply Comments of AT&T Inc.," Jan. 7, 2013.

3 There is agreement that a spectrum screen should protect competition and prevent foreclosure

This comment is primarily a response to a reply comment from AT&T⁴ in the Notice of Proposed Rulemaking⁵ on spectrum holdings for commercial mobile radio services (CMRS). I focus on this particular reply comment because it includes submissions from outside authors (Jeffrey Reed & Nishith Tripathi,⁶ Mark Israel & Michael Katz⁷) who say that they were specifically asked by AT&T to respond to my initial comment⁸ in this proceeding. Moreover, these authors have a record of achievement, so their responses deserve consideration. Nevertheless, even these authors were unable to make a strong case for weighing all spectrum equally regardless of frequency, as I will show. In this comment, I will point out some of the points of agreement, and there are many, as well as points of disagreement.

One point of agreement is that the goal of a spectrum screen is to protect future competition. Competition motivates carriers to decrease prices, increase quality of service, and innovate. The policy goal should not be to protect the interests of any particular carrier or carriers. As Drs. Israel and Katz said, "spectrum policy should protect competition, not competitors."

More specifically, there seems to be agreement that one important function of a spectrum screen is to prevent foreclosure, i.e. "when a firm weakens competition by reducing its access to customers or inputs" such as spectrum, and agreement that foreclosure is possible in the absence of any spectrum screen. According to Drs. Israel and Katz, there is a risk that a firm might engage in foreclosure if doing so "could raise the costs of actual and potential rivals sufficiently to lead to significantly higher prices and/or lower quality." There is agreement that this is a risk if a firm can gain exclusive rights to too much spectrum in a given market. Where we disagree is whether the frequency of the spectrum that the rival can access matters when assessing this risk. As this comment and its predecessor show, a firm is far better able to increase the costs a rival must incur if the firm can block that rival's access to low-frequency spectrum.

⁴ "Reply Comments of AT&T Inc.," Jan. 7, 2013.

⁵ Federal Communications Commission, Notice of Proposed Rulemaking in the matter of Policies Regarding Spectrum Holdings, WT Docket No. 12-269, Sept. 28, 2012. http://www.fcc.gov/document/mobile-spectrum-holdings-nprm

⁶ J. H. Reed & N. D. Tripathi, "The Value of Spectrum: A Response to Jon M. Peha's Paper," pp. 54-73 of "Reply Comments of AT&T Inc.," Jan. 7, 2013. Henceforth Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013.
⁷ M. A. Israel & M. L. Katz, "Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings," pp. 140-183 of "Reply Comments of AT&T Inc.," Jan. 7, 2013. Henceforth Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013.

⁸ Peha, "Updating the Spectrum Screen," Nov. 28, 2012.

⁹ M. A. Israel & M. L. Katz, "Economic Analysis of Public Policy Regarding Mobile Spectrum Holdings," p. 106 of "Comments of AT&T Inc.," in the matter of Policies Regarding Spectrum Holdings, WT Docket No. 12-269, Nov. 28, 2012. http://apps.fcc.gov/ecfs/document/view?id=7022068061

¹⁰ H. Ergas and E. K. Ralph, "New Models of Foreclosure: Should Antitrust Authorities Be Concerned?," Feb. 1998. http://ssrn.com/abstract=55775

¹¹ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 149.

¹² Peha, "Updating the Spectrum Screen," Nov. 28, 2012.

4 There is greater risk of foreclosure if a firm dominates low-frequency spectrum in rural areas.

The capital and operating costs incurred by a cellular provider for an infrastructure that serves a large area are both roughly proportional to the number of cells in that area. In rural areas, the size of a cell and therefore the number of cells needed to cover a region greatly depends on the lowest-frequency spectrum that the cellular provider has access to. This appears to be an area of agreement. As Drs. Reed and Tripathi wrote, operators using spectrum at a higher frequency must "adjust the distances between transmitter and receiver," which means changing cell radius. The disagreement is over whether the frequency-dependent differences in cell size and cost could affect competition.

Figure 1 shows how infrastructure cost depends on frequency in an example scenario where a carrier wishes to blanket a rural region with cellular coverage in a 10 MHz band. (See previous filing¹⁴ for details of how this was calculated.) As the figure shows, if carrier A's lowest frequency holding is at 700 MHz and carrier B's is at 1400 MHz, carrier B's costs for bringing ubiquitous coverage would be roughly twice that of carrier A's. Carrier B can either spend much more deploying and operating its infrastructure, and offer "significantly higher prices" to cover these costs, or it can provide service that covers highways and population centers but is not ubiquitous which means significantly "lower quality." This is consistent with the risk of foreclosure as described above by Drs. Katz and Israel, i.e. lack of access to low-frequency spectrum leads "to significantly higher prices and/or lower quality."

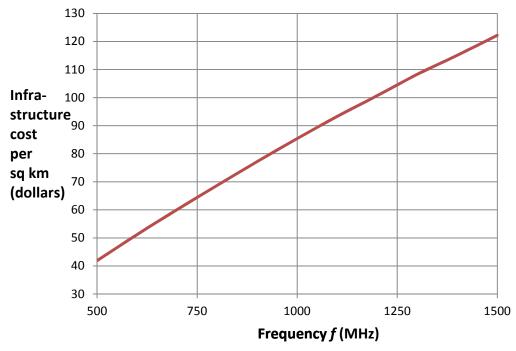


Figure 1: Cost of cellular infrastructure per square km as a function of frequency f in the rural scenario from ¹⁵

¹³ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 59.

¹⁴ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 6-8.

¹⁵ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 6-9.

If a spectrum screen does not weight based on frequency, a single firm can control all of the CMRS spectrum under 1 GHz, thereby keeping that spectrum from competitors, without holding more than one third of all CMRS spectrum. This problem will get worse over time, because the FCC is likely to make more spectrum at high frequencies available for mobile services, thereby reducing the fraction under 1 GHz. ¹⁶

Drs. Irvine and Katz make a curious counterargument that those areas where the analysis described above applies are "areas with no significant risk of foreclosure." This is untrue. A screen must protect against foreclosure in both urban and rural areas. Indeed, because the cost of spectrum per MHz-square-mile is usually lower in rural areas (at least when the secondary market for spectrum is functioning well), it would initially be easier for a firm that is pursuing a strategy of foreclosure to build up its spectrum holdings in rural areas. Also, as the next section will show, what happens in rural areas affects what happens in urban areas.

Drs. Israel and Katz do perform quantitative analysis that they claim supports their hypothesis. In particular, they show the relationship between market share HHI and what they call "populationweighted spectrum share HHI."18 They find that market share HHI is inversely correlated with "population-weighted spectrum share HHI," and there is what they characterize as a "weak correlation" between market share and population-weighted spectrum share." I applaud these authors for bringing hard evidence and analysis to spectrum policy debates, but this approach has fatal flaws. I do not fully agree with what could be concluded from these graphs and correlations even if they show what the authors claim, but they do not, so interpretation is pointless. The authors never explicitly define "population-weighted spectrum share HHI," but it appears to involve the same calculation typically used to look at market concentration, except with "population-weighted spectrum share" instead of market share. Although the assumption is never stated explicitly, it appears that the authors assume that all spectrum should be counted equally towards spectrum share regardless of frequency, just as all customers are counted equally towards market share. But whether all spectrum can be treated the same regardless of frequency is the issue in question. This is akin to quietly assuming that 2+2=5, using that assumption to perform analysis, and claiming that the results prove that 2+2=5. (It is also difficult to learn from these results because they are derived from AT&T proprietary data, which makes close examination impossible.)

5 Nationwide weighting should reflect the impact of frequency throughout the nation, including rural, suburban and urban areas.

If one were designing a cellular system that would only serve dense urban areas, frequency band would be relatively unimportant. Drs. Reed and Tripathi and I agree that in these urban areas, low-frequency spectrum has some disadvantages, but this is only a part of the story. While Drs. Reed and Tripathi

¹⁶ There has been debate over whether spectrum below 1 GHz should be viewed differently from spectrum above 1 GHz in this context. While spectrum at 999 MHz is not qualitatively different from spectrum at 1001 MHz, there are certainly important differences between CMRS spectrum at 900 MHz and CMRS spectrum at 1.9 GHz or higher. Thus, if we consider which spectrum that has been allocated to CMRS so far, the 1 GHz distinction clearly does matter.

¹⁷ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 151.

¹⁸ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, pp. 151-158.

discuss these advantages at length, ¹⁹ they fail to even mention that there are significant disadvantages as well. For example, consider a mobile phone user who is in a building with thick walls near the edge of a cell. At lower frequencies, it is possible to design systems such that this customer is more likely to be able to transmit successfully to the nearest cell tower, and to do so at lower transmit power thereby reducing battery consumption, than is possible at high frequencies. Drs. Reed and Tripathi present no evidence that disadvantages of lower frequencies outweigh advantages, and I will present no evidence that advantages outweigh disadvantages. Instead, I point out that the differences between high-frequency and low-frequency spectrum in urban areas are small compared to the differences in rural and suburban areas, and unless a carrier plans only to serve big cities, this matters even when designing urban infrastructure.

Drs. Reed and Tripathi and I agree that a carrier that operates in a given band in one region would prefer to operate in that same band in other regions. This simplifies handset design, which can reduce cost. As Drs. Reed and Tripathi point out, it also helps by "avoiding the performance costs needed for handover." Where we seem to disagree is on the implications of this, but clearly any carrier with aspirations of providing nationwide service must cover urban, suburban and rural areas, and it can do so at lower cost if it can access some low-frequency spectrum. Consider the following three cases: (i) a carrier has 40 MHz of spectrum nationwide in the 700 MHz band, (ii) a carrier has 40 MHz of spectrum nationwide in the 1.8 GHz band, (iii) a carrier has 40 MHz of spectrum in the 1.8 GHz band in urban areas (i.e. those regions with population density above a given threshold) and 40 MHz of spectrum in the 700 MHz band everywhere else. Case 1 leads to lower costs than case 2, because fewer cells are needed, as shown in Section 4. Historically, case 1 has led to lower costs than case 3, because case 1 handsets only need to operate on 40 MHz, and case 3 handsets must operate on 80 MHz and handoff between bands as needed. Thus, having the 40 MHz of spectrum in urban areas in the lower-frequency band reduces cost.

As discussed in my initial filing,²¹ the disadvantages of operating in multiple bands is probably decreasing over time. The day may or may not come when these disadvantages are small enough to be ignored. If it does, this might lead one to conclude that the weights in rural and urban should be different, and weights should depend greatly on frequency in the former but not the latter. However, it does not appear that this is the case as of 2013,^{22,23} and even if it is, this is not what proponents for equal weighting such as AT&T and Verizon are calling for; they want equal weighting nationwide.

I also agree with Drs. Reed and Tripathi when they argue that nationwide weights should not be set based on characteristics of rural markets alone.²⁴ This was never my proposal. Where we differ is that Drs. Reed and Tripathi believe that the FCC "should adopt its policy based on circumstances in dense urban areas"²⁵ alone, and I believe that the FCC should adopt policy based on a combination of rural, suburban, and urban circumstances. After all, while many Americans do live in urban areas, the vast

¹⁹ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, pp. 63-65.

²⁰ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 61.

²¹ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 12.

²² Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 12.

²³ Federal Communication Commission Technological Advisory Council, Multiband Devices Working Group, Presentation at the FCC on Sept. 24, 2012. http://transition.fcc.gov/bureaus/oet/tac/tacdocs/meeting92412/TAC-9-24-12-Presentations.pdf

Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 57.

²⁵ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 57.

majority of the country by area is rural or suburban, and nationwide carriers want handsets that work in most of this area.

6 Bandwidth and frequency both affect the value of spectrum, and both should be considered in a screen.

As presented in my previous submission, ²⁶ the market value of high-frequency spectrum is less than that of low-frequency spectrum, and this is not disputed by Drs. Israel and Katz or Drs. Reed and Tripathi. The disagreement is over whether this should matter in the spectrum screen. As Drs. Israel and Katz wrote, "to the extent that high-frequency spectrum necessitates greater additional cost to achieve a certain degree of capacity expansion, all else being equal, the price of that spectrum is expected to be lower, thus offsetting the higher cost of expansion. ... As such, there is no reason to believe that a firm that has to rely on 'bad' spectrum will have to pay more in total to enter or expand and, thus, there is no implication that such a firm will be foreclosed."²⁷ Drs. Reed and Tripathi echo this view.²⁸ This argument is demonstrably wrong for a number of reasons.

Drs. Israel and Katz argue that a spectrum screen is needed for every cellular market area (CMA), that the screen should take into account the bandwidth of every license in that CMA, but the screen should not take into account frequency of these licenses because the greater value of a low-frequency license is reflected in its market price. However, the greater value of a high-bandwidth license is also reflected in its market price in exactly the same way, so Israel and Katz's argument should require us to give equal weight to a 25 MHz license and a 10 MHz license in the screen calculation. After all, a carrier can overcome the small bandwidth of its spectrum holdings by building more cells than its competitors, just as a carrier can overcome the high frequency of its spectrum holdings by building more cells. There is no plausible reason to include one of these important factors and not the other, which shows that there is an error in Drs. Israel and Katz's argument.

The problem with Drs. Israel and Katz's argument is fundamental. Their argument disregards the very purpose of a spectrum screen. They rely on the assumption that a firm that wants to enter a market or expand will be able to obtain spectrum at an equilibrium price which reflects the cost of building out at that frequency. Drs. Israel and Katz say that "any economically relevant differences in spectrum characteristics will be reflected in equilibrium license prices." This ignores the aspects of the spectrum market that led to the screen. The secondary market for spectrum licenses in a given CMA has very few buyers and sellers, so there is a risk that the strategy of just one firm will greatly affect market price. This is a well-known cause of market failure. Even worse, this is a market in which a firm must buy from its direct business competitors rather than some neutral upstream supplier. To add uncertainty and instability, auctions occur sporadically at intervals that are difficult to predict. Each auction expands the amount of spectrum available, instantly quenching the spectrum-thirst of some firms and greatly reducing their demand, but generally only temporarily. In the best of times, it is risky to assume that a firm in such a market can obtain spectrum whenever it wishes at a reasonable equilibrium price. Moreover, the spectrum screen should not be designed for the best of times. When one or more firms control so much spectrum in a market that competition is undermined, or there are firms that plan to

²⁶ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 12-14.

 $^{^{\}rm 27}$ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 161.

²⁸ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 59.

²⁹ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 145.

expand their spectrum holdings in a deliberate strategy of foreclosure, prices are more likely to greatly exceed any theoretical equilibrium, or price may be irrelevant because there is simply no spectrum on the market in a given CMA. In effect, without ever stating their assumption, Drs. Israel and Katz have assumed that the conditions in which a spectrum screen is needed most will never arise, and then used this bad assumption to argue that a spectrum screen needn't consider frequency.

Drs. Israel and Katz³⁰ and I³¹ both argued that the weights for a spectrum license should not be derived from the auction price of that license alone. Although auction prices do reflect important intrinsic qualities of the spectrum that deserve consideration such as bandwidth, frequency, and area covered, they also reflect other factors that have little to do with the spectrum itself, such as the state of the national economy at the time of the auction. However, we disagree on whether this data is useful at all. If one averages over enough samples,³² auction prices can be quite valuable for determining what a spectrum screen should look like. FCC staff could certainly do this kind of analysis. The prices of licenses in a secondary market would also be useful if enough of this data is available.

7 Assigning an equal weight to all frequency bands is arbitrary.

As far as I know, no remotely plausible argument has ever been advanced to support the idea of treating 10 MHz of spectrum at 700 MHz the same as 10 MHz of spectrum at 3 GHz. AT&T tried by arguing that "the data carrying capacity of all spectrum, however, is equal: 20 MHz of AWS spectrum can carry as much wireless broadband traffic as 20 MHz of 700 MHz spectrum." This would be a powerful argument if there were any truth to it, but there isn't, as shown in my previous filing. 34

Drs. Reed and Tripathi argue that "average throughput (i.e., the average bits per second supported) is not defined by the spectrum frequency, but rather is a function of the signal-to-interference plus noise ratio (SINR or SIR) that can be achieved." Strictly speaking, this statement is true, at least if we are talking about a point-to-point link, but it is just as true that average throughput is not defined by the spectrum bandwidth, so why should the bandwidth of each license matter in a spectrum screen and not the frequency of each license? It is possible to increase throughput of a link by decreasing distance between transmitter and receiver, which increases SINR. In the case of cellular, it is possible to increase throughput by decreasing cell size and therefore using more cells to cover a given region. If it has enough cells, a carrier with 10 MHz of AWS spectrum can have more capacity than a carrier with 100 MHz of AWS spectrum.³⁵ Thus, any discussion of the inherent "data-carrying capacity" of a block of spectrum allocated for CMRS is technically meaningless and always incorrect. We must look elsewhere for a rational way to judge CMRS spectrum holdings.

All sides of this debate agree that spectrum in different frequency bands has different physical properties, as discussed in Sections 4-5. All sides agree that spectrum at different frequency bands has different market values, as discussed in Section 6. To treat 20 MHz of spectrum in the 700 MHz band

³⁰ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 159.

³¹ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 12-13.

³² Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 12-14.

³³ AT&T, Supplemental Reply Comments of AT&T, in the matter of The State of Mobile Wireless Competition, WT Docket No. 11-186, April 30, 2012, p. 5. http://apps.fcc.gov/ecfs/document/view?id=7021914823

³⁴ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 3-4.

³⁵ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 3-4.

the same as 20 MHz of spectrum in the AWS band because they have a number in common is as arbitrary as treating 100 U.S. dollars the same as 100 Hong Kong dollars. Relying on superficial similarities saves us the trouble of figuring out what the conversation rate should be, but it also leads to bad decisions. (Nevertheless, we should not be surprised if holders of Hong Kong dollars think it is obvious that all dollars should be viewed as equivalent.³⁶)

Consider the admittedly unlikely scenario in which it is discovered how to make U.S. wheat and only U.S. wheat into a perfect substitute for oil, and policymakers are concerned that one firm will gain control over enough land to undermine competition in the new wheat-energy sector. It is possible to grow wheat in Kansas. It is also possible to grow wheat in the Nevada desert, although at much greater cost per bushel. Would policymakers limit the fraction of land that a wheat-grower can own and treat a square mile in Kansas the same as a square mile in the Nevada desert? Doing so would be arbitrary, just as treating a MHz of 700 MHz spectrum like a MHz of 3.5 GHz spectrum in a spectrum screen is arbitrary.

Unlike those arguing for equal weights at all frequencies, I have proposed a reasonable basis by which spectrum holdings should be compared that is not arbitrary. The weight of a license for spectrum at a given frequency should "reflect the extent to which spectrum at that frequency yields lower costs for the deployment and operation of equipment,"³⁷ just as the weight of a license of given bandwidth should reflect the extent to which spectrum with that bandwidth yields lower costs. Thus, "if a carrier has a bandwidth of B_i at frequency f_i for different values of i, then the effective size of the carrier's holdings is $\sum_{\forall i} w_i(fi) * B_i$

8 These arguments apply to all spectrum that is used to blanket a region with cellular coverage, regardless of frequency.

The general arguments and policy recommendations in this comment and the previous filing apply to all frequency bands allocated to CMRS. Of course, when numerical results are presented for specific example scenarios, the numerical results are built on example-specific assumptions. This yielded some interesting attacks from responders.

As described in my previous filing, "the screen we are developing here should be specifically for terrestrial (i.e. non-satellite) CMRS spectrum holdings,"³⁹ and more specifically spectrum used for "wide area coverage"⁴⁰ as opposed to uses with very different engineering-economics such as "small femtocells hotspots or wireless backhaul."⁴¹ This filing also provided quantitative results in the form of equations and graphs for some specific rural and suburban example scenarios. In these example scenarios, I used "the Hata Model for path loss in an open area. This is the industry-standard model for regions where there are relatively few obstructions (such as buildings), and where the frequency falls between 200 MHz and 1.5 GHz."⁴² Thus, the numerical results were only valid between 200 MHz and

³⁶ At the time of writing, 100 Hong Kong dollars can be exchanged for 13 U.S. dollars.

³⁷ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 4.

³⁸ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 5.

³⁹ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 4.

⁴⁰ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 4.

⁴¹ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 4.

⁴² Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 7.

1.5 GHz. Because assumptions should be stated clearly to the reader in any comment to the FCC, the comment indicated that "further work is needed to find a weighting function that represents the best balance. This should include consideration of frequency bands above 1500 MHz, which are beyond the scope of this comment." This meant only that the equations did not apply above 1500 MHz; the concepts apply to all bands used by CMRS providers for terrestrial wide-area coverage.

Based on this statement, Drs. Israel and Katz make the disappointing and obviously incorrect assertion that "Professor Peha himself apparently recognizes that his estimates are invalid at higher frequencies, and he limits the scope of his comments to frequencies below 1500 MHz." 44

Of course, the models can be extended to higher frequencies by replacing the Hata path loss model that is valid below 1500 MHz with the COST-Hata path loss model that is valid above 1500 MHz, re-deriving the equations with this path model, putting in the numerical values as appropriate, and extending the graph. Qualitatively, the results would be the same in that the number of cells needed and therefore cost would continue to increase dramatically with frequency, but quantitatively the results would differ a bit. Drs. Israel and Katz chose a more amusing approach. They extended the curves beyond 1500 MHz using an equation that is not valid above 1500 MHz. Then they point to what they believe to be anomalies in the incorrect results that they produced on their own, and they claim that this invalidates my analysis. 45

That is not the only error in their criticism of this graph. Although I would never suggest that the FCC give any spectrum band a weight less than 0, I do expect that the curve presented for the rural scenario⁴⁶ will eventually go negative as frequency increases, and this was apparently troubling to both Drs. Israel and Katz⁴⁷ and Drs. Reed and Tripathi. ⁴⁸ This does not mean spectrum at this frequency is worthless. As explained in the comment, if the value of this curve is negative at 1500 MHz, for example, it "would mean that carriers would rather pay for spectrum at 700 MHz than gain access to spectrum at 1500 MHz for free."49 This curve was based on two assumptions that were explicitly stated: that 700 MHz spectrum is available to the rural carrier at the mean price per MHz-POP of the 2008 spectrum auctions, and that this carrier wants spectrum because it "wishes to blanket a rural open area with 10 MHz of spectrum."⁵⁰ A carrier may still be willing to pay for higher-frequency spectrum when these two conditions do not apply, even when the value in this particular graph is negative. As discussed in Section 6, a carrier clearly does not always have the option of getting 700 MHz spectrum at the 2008 auction price, so high-frequency spectrum may be the best option available, or the only option. If the price at the reference frequency of 700 MHz spectrum is greater than the 2008 price, then the entire curve must be shifted upwards. Alternatively, a carrier may want spectrum for a purpose for which the penalty for operating at high frequency is less severe than when covering a large area, such as deploying a small cell to expand capacity at a busy intersection.

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 $^{^{\}rm 43}$ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 11.

⁴⁴ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 163.

⁴⁵ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, pp. 163-164.

⁴⁶ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 9.

⁴⁷ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 163.

⁴⁸ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, pp. 57-58.

⁴⁹ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 9.

⁵⁰ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 9.

9 It is easy to define and implement a weighting function that is better than current policy.

To implement a weighting function, all the FCC has to do is specify the function $w_i(f)$ in Section 7. Any carrier that has at least one employee with high school math skills or better should be able to apply that equation. Thus, there is no truth to the unsupported assertion by Drs. Israel and Katz that "even if there were a theoretically sound basis for a differential weighting scheme (and none has been presented), it would be very difficult to implement such a scheme in practice."⁵¹

What is difficult is finding a weighting function that is optimal in some sense, but this is not an argument against proper weighting, since finding a weighting function better than the current policy is easy. While trying to fill an opening in my research lab this spring, I received resumes from five outstanding candidates. By AT&T's logic, I should select a sixth applicant who is blatantly unqualified, so I can avoid the trouble of choosing among the five strong applicants.

I was also criticized for not proposing a specific weighting function.⁵² Choosing a specific weighting function is certainly possible. It would benefit from access to more data than I have, and more staff time than I have, but this should not be a problem for FCC staff. This much is clear: the weighting function $w_i(f) > 0$ for all positive frequencies f and the derivative $w'_i(f) < 0$ for all positive frequencies f. A promising candidate would be

$$w_i(f) = e^{-\alpha f}$$

for a positive constant α . The results of Kerans et al. ^{53,54} would suggest $\alpha = .001$ MHz⁻¹ based on their analysis of auction data, but I have argued that more data should be included in analysis before reaching a solid conclusion. ^{55,} AT&T is arguing for $\alpha = 0$, but the data clearly point to a greater value of α .

Drs. Israel and Katz also express fear that the process of fully specifying a reasonable spectrum screen "would be subject to intense lobbying and rent-seeking activities." This is true, but alas, even sticking with a spectrum screen policy that no longer makes sense will not prevent lobbying or rent-seeking. Indeed, Drs. Israel and Katz's words about the danger of lobbying appear in a document that AT&T filed in order to lobby the FCC on this very issue.

10 The major conclusions are not very dependent on specific assumptions.

Drs. Reed and Tripathi questioned some specific assumptions that were made to get numerical results in example scenarios. However, even if they are right in all of these criticisms (which is not the case), changing these assumptions would not change the fundamental conclusion that a carrier is at a significant disadvantage with respect to cost or quality (i.e. ubiquity) or both if it must operate only at

⁵¹ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 164.

⁵² Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 65.

⁵³ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 12-14.

⁵⁴ A. Kerans, D. Vo, P. Conder, S. Krusevac, "Pricing of Spectrum Based on Physical Criteria," *Proceedings of IEEE DySPAN*, 2011, pp. 223-230.

⁵⁵ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 13.

⁵⁶ Israel & Katz, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 165.

high frequencies. The core findings from the quantitative analysis in my initial comment are not really in question.

For instance, in the example rural scenario, I assumed that cellular connections could span up to 80 km when operating at 700 MHz, on the grounds that a number of vendors such as Motorola⁵⁷ have publicly stated that the new generation of cellular technology (LTE) will support distances up to 100 km.⁵⁸ Drs. Reed and Tripathi assert that these vendor claims are unachievable: "Because of the earth's curvature, such distances cannot be achieved by cell towers that comply with zoning restrictions and that can be feasibly constructed ."⁵⁹ Even if Drs. Reed and Tripathi are right, this would mean that maximum cell size would decrease for all frequencies, and the conclusion that costs are far greater in higher frequencies would remain the same. This is demonstrated in Figure 2, which shows cost under the same assumptions as Figure 1, except that maximum cell radius has been reduced from 80 km to 40 km, i.e. just 40% of what vendors are claiming.

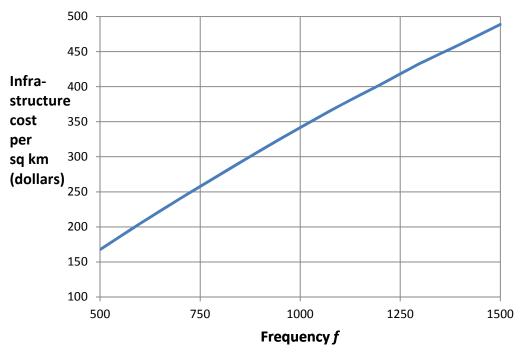


Figure 2: Cost of cellular infrastructure per square km as a function of frequency f in the rural scenario from 60 , except with a maximum cell radius of 40 km

Drs. Reed and Tripathi also claim, incorrectly, that my example scenario for a rural area "implicitly assumes that the hypothetical purchasers of spectrum will be building out an entirely new green-field network in an area where there are no existing cell towers." However, they are correct when they say that a carrier that is building out in an area where it does not currently provide service can build new

⁵⁷ Motorola white paper, *TD-LTE: Exciting Alterative, Global Momentum,* 2010. http://www.motorola.com/web/Business/Solutions/Industry%20Solutions/Service%20Providers/Network%20Operators/ Documents/ static%20files/TD-LTE%20White%20Paper%20-%20FINAL.pdf

⁵⁸ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 7.

⁵⁹ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 67.

⁶⁰ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 6-9.

⁶¹ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 60.

towers, or lease space on the towers used by competitors. The former requires more capital expenditures (CAPEX), and the latter more operational expenditures (OPEX). In this example scenario, "to obtain numerical cost results, we assume that the net present value (NPV) of building a cell tower and operating it every year is one million dollars." No assumptions were made about how much of this \$1 million is CAPEX and how much is NPV of OPEX, so this model can apply to new towers or leasing arrangements. Drs. Reed and Tripathi never indicate why they think this model assumes that new towers must be built. Perhaps they would prefer a smaller mean NPV of CAPEX + OPEX if they believe leasing is less inexpensive in the long term. Again, this would change some cost numbers for both high and low-frequency systems, but the shape of the curve would be similar, and the conclusions unchanged. This is shown in Figure 3, which is based on the same assumptions as Figure 1, except that the mean NPV for both deploying and operating a tower over the long term has the bargain price of \$500 thousand instead of \$1 million.

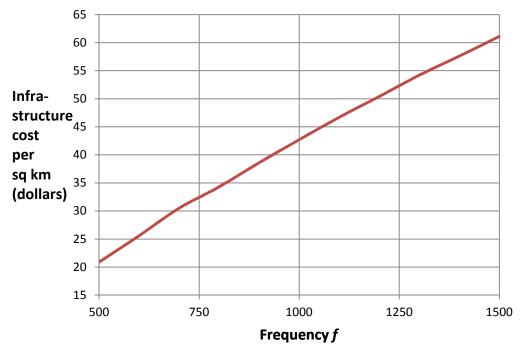


Figure 3: Cost of cellular infrastructure per square km as a function of frequency f in the rural scenario from ⁶³, except that the NPV of deploying a cell site and operating it over the long term is \$500 thousand million

Drs. Reed and Tripathi argue that the example suburban scenario is unrealistic, because it is a case where cells are larger than can be accommodated with higher-frequency spectrum, but small enough that lower-frequency spectrum can provide ubiquity. ⁶⁴ If they are right, then the value and utility of higher-frequency spectrum is even worse than I have stated. If all cells must be small enough to accommodate the highest frequency spectrum that a carrier holds in that region, then adding higher-frequency bands to one's portfolio means adding an even larger number of cells than I would estimate. (Although agreeing with them on this point would strengthen the case for frequency-based weights, I must respectfully disagree.)

⁶² Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 7.

⁶³ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, pp. 6-9.

⁶⁴ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 70.

Drs. Reed and Tripathi also raise other minor issues regarding analysis of this example suburban scenario. They dispute the use of Shannon's theorem to calculate throughput. They are correct that actual throughput is not exactly equal to the value derived using Shannon's equation, but this difference is relatively small, and applies to both high and low frequencies. They also criticize my assumption that in the higher-frequency band in this particular scenario, "interference + noise is roughly the same at all frequencies, which is reasonable in cases where the maximum radius at the frequencies considered here is well under the actual radius of the cell." Even if they are correct that the frequency-dependent variation of interference + noise is non-negligible, which I question, this would change numerical results only slightly, and would not change the trends or the conclusions.

If the debate is over *precisely how much* less to weigh high-frequency spectrum, then I encourage comments and suggestions like those described above from knowledgeable contributors like Drs. Reed and Tripathi. Quibbling over these minor details will help us to choose the right models and populate those models with the right numerical values. However, as long as the debate is over *whether* to weigh high-frequency differently, these points are unimportant.

11 Conclusions

These comments have shown that a spectrum screen that treats high-frequency and low-frequency spectrum the same is arbitrary and illogical. To protect competition, any assessment of a carrier's spectrum holdings in a given market should reflect the extent to which access to that spectrum would allow a rival firm that wants to expand or enter the market to deploy and operate a cellular system at reasonable cost. This is only possible if the FCC considers both the frequency and bandwidth of each license when measuring their cumulative magnitude against a spectrum screen. The evidence that higher-frequency spectrum is less valuable to a CMRS provider is irrefutable based on the economic data, and expected based on the physical properties of electromagnetic waves. A carrier that cannot get access to low-frequency spectrum may need many more cells, which can be costly. Israel and Katz tried to argue that the frequency-dependent differences in spectrum licenses do not matter, but their arguments are riddled with conceptual errors and contradictions. In particular, they are designing a screen while assuming that spectrum will always be readily available at equilibrium prices, which means they are designing a screen that will fail to protect competition precisely when the screen is needed most.

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⁶⁵ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 72.

⁶⁶ Reed & Tripathi, "Reply Comments of AT&T Inc.," Jan. 7, 2013, p. 71.

⁶⁷ Peha, "Updating the Spectrum Screen," Nov. 28, 2012, p. 10.